8 Differential Leveling Survey Specifications

Survey specifications describe the methods and procedures needed to attain a desired survey standard. Specifications in this section are based on Federal Geodetic Control Subcommittee (FGCS) standards and specifications. Except where noted, they have been modified to give results that will meet the requirements for various types of differential leveling surveys typically performed by Caltrans. For details regarding standards, refer to Section 5, "Accuracy Classifications and Standards".

Caltrans differential leveling survey specifications are to be used for all Caltrans-involved transportation improvement projects, including special-funded projects.

8.1 Differential Leveling Method

These specifications apply to the use of compensator-type engineer's levels and electronic digital/bar code leveling systems. Specifications for trigonometric leveling are covered in Section 7, "Total Station Survey System (TSSS) Survey Specifications." Specifications for GPS derived elevations are covered in Section 6, "Global Positioning System (GPS) Survey Specifications."

Equipment to be used is specified under "Method" for each order of accuracy in this Section.

All differential leveling equipment must be properly maintained and regularly checked for accuracy. Systematic errors due to poorly maintained equipment must be eliminated to ensure valid survey adjustments. Equipment acquisition, repair, adjustment, and maintenance is covered in Section 3, "Survey Equipment."

8.2 General Differential Leveling Survey Specifications

8.2-1 Sight Distances

Sight distances and the balance between foresights and backsights are critical to maintaining accuracy in differential leveling. Sight distances should be reduced when poor environmental conditions are encountered. Under normal conditions the specified sight distances in this Section will produce surveys that meet Caltrans accuracy standards for second-, third-, and general-order surveys. See "Limits of Sight Distances," page 8-5.

8.2-2 Turning Points

Turning points (TP) should be set in stable, protected locations. Spikes or large nails set in pavement; wooden stakes set in firm soil; prominent points such as rock outcroppings or the top of concrete curbs may be used as turning points. Each turning point should have a definite high point or be marked at the exact point of rod contact.

Turning points should not be removed after use, but left in place to provide a check in the event of blunders or excessive misclosures. A solid, well defined turning point may be used as a temporary bench mark (TBM).

8.2-3 Benchmarks

Establish benchmarks with physical characteristics and quality commensurate with the order of the leveling survey. Benchmarks should be of a stable, permanent nature; e.g., galvanized steel pipe; steel rod driven into a firm soil base; or poured in place concrete. A brass Caltrans disk epoxyed into a drill hole in rock or concrete is also acceptable.

Benchmarks should be conveniently located and easily accessible. Whenever possible, benchmarks should be located outside of construction areas, clear of traffic, and within a public right of way or easement. Allow for future changes in landscaping and overgrowth of trees and foliage.

Space benchmarks as required by project conditions and convenience of operation, generally not to exceed 1 km apart. Minimum spacing for benchmarks is normally 300 m. Prepare a written benchmark/station description for inclusion in the survey notes and in the benchmark summary report.

8.2-4 Differential Leveling Survey Notes

Rod readings for single- or three-wire leveling operations using a compensator-type engineer's level, should be recorded in digital form on a hand-held programmable calculator, computer or data collector. Such calculators must produce a hard copy of all readings, reductions, and adjustments. Hard copies of data collection, reduction, and adjustment calculations will be incorporated into, and become a permanent part of the survey field notes. See Section 14, "Survey Records." Field notes can be recorded by hand on Caltrans forms HCS-88 or DH-SP-14.

Raw field data generated by an electronic digital/bar code leveling system will be translated into field book format by use of conversion software such as "DIGILEV Translation Program" or "STARPLUS Data Conversion Utility".

8.2-5 Adjustment of Differential Leveling Surveys

Second- and third-order differential leveling surveys, when run as a single loop or section, are adjusted by a straight-line interpolation process. Corrections for the closing error will be prorated to each benchmark and TP between the two controlling benchmarks.

When multiple leveling survey loops interconnect to form a network, such as in corridor or project control, points common to two or more loops will be adjusted by application of least-squares adjustment. See Section 5.4 "Least Squares Adjustment."

8.3 Second-Order Differential Leveling Surveys

8.3-1 Application

Second-order leveling surveys are generally confined to extending vertical control data over long distances, and establishing and maintaining corridor vertical control.

For second-order differential leveling specifications acceptable to the National Geodetic Survey, see *Standards and Specifications for Geodetic Control Networks* published by the Federal Geodetic Control Committee, September, 1984.

8.3-2 Equipment

Differential leveling survey methods/equipment to achieve second-order standards are:

- Compensator-type (automatic) engineer's level (three-wire observations) with an invar-tape yard rod or a suitable metric graduated invar-tape rod.
- Electronic digital/bar-code leveling system with one-piece invar rod.
- If matched rods are used they must be alternated (leapfrogged) between setups.

8.3-3 Second-Order Three-Wire Differential Leveling Surveys

Instrument Check

At the beginning and end of each day's operation, check the instrument for collimation error (two peg test), recording the tests into the survey notes. Description of the two peg test can be found in any standard surveying text. If an error in excess of 2 mm within a 60 m sight distance is detected, the level should be readjusted. If the instrument is severely jolted or bumped, or suspected as such, it should be immediately checked. Compensator-type instruments should be checked for proper mechanical operation at least every two weeks of use.

Limits of Sight Distances

Sight distances should not exceed 70 m. When more than two rod readings (see Rod Readings, below) are rejected in every ten setups, reduce the sighting distance. The difference in length between foresights and backsights of a single setup should not exceed 5 m.

Rod Readings

Rod readings are estimated to the nearest 1 mm (0.001 yard, if using a yard rod). For each foresight and backsight reading of a set, the middle wire reading must be within 1 mm (0.001 yard, if using a yard rod) of the mean of all three wire readings. If this is not achieved, the misread or misrecorded wire must be identified and corrected before moving to the next setup.

See Table 8-1 for second-order, three-wire differential leveling standards and specifications.

8.3-5 Second Order, Electronic Digital/Bar Code Rod Leveling System

Manufacturers specifications recommend that the electronic digital leveling instrument should not be exposed to direct sunlight. Umbrellas should be used in bright sunlight. When using electronic digital leveling instruments, the absolute collimation error will be recorded along with the leveling data.

See Table 8-1 for second order electronic digital/bar code differential leveling standards and specifications.

Table 8-1 Second-Order Differential Leveling Specifications

OPERATION/SPECIFICATION	COMPENSATOR-LEVEL THREE-WIRE OBSERVATION	ELECTRONIC/DIGITAL BAR CODE LEVEL
Difference in length between fore and back sights, not to exceed per setup	5 m	5 m
Cumulative difference in length between fore and back sights, not to exceed per loop or section	10 m	10 m
Maximum sight lengths	70 m	70 m *(See Note 1)*
Minimum ground clearance of sight line	0.5 m	0.5 m
Maximum section misclosure	$8\ \text{mm} \times \sqrt{D}$ *(See Note 2)*	$8\ \text{mm} \times \sqrt{D}$ *(See Note 2)*
Maximum loop misclosure	$8\ \text{mm} \times \sqrt{E}$ *(See Note 3)*	$8\ \text{mm} \times \sqrt{E}$ *(See Note 3)*
Difference between top and bottom interval not to exceed:	0.20 of rod unit	N/A
Collimation (Two-Peg) Test	Daily (not to exceed 2 mm) *(See Note 4)*	Daily
Minimum number of readings. (Use repeat measure option for each observation.)	N/A	3 *(See Note 5)*

Notes

1. Leveling staff in backlit condition may decrease maximum sight distance.
2. D = Shortest one-way length of section in km (section is defined as an unbroken series of setups between two permanent control points).
3. E = Length of loop in km (loop is defined as a series of setups closing on the starting point).
4. Readjust level if 2 mm in 60 m is exceeded.
5. If standard error exceeds 0.1 mm, continue repeat measurements until standard error is less than 0.1 mm.

8.4 Third-Order Differential Leveling Surveys

8.4-1 Applications

Third-order leveling surveys are used to establish vertical control and maintain benchmarks for:

- Project Control
- Supplemental Control
- Photo Control
- Construction Survey Control
- Topographic Survey Control
- Major Structure Points

8.4-2 Specifications

Methods:

- Compensator-type engineer's level (three-wire method) and yard rod or metric graduated Philadelphia-style rod
- Compensator-type engineer's level (single-wire method) and metric graduated Philadelphia-style rod
- Electronic/digital level and bar-code rod (wood or non-invar metal)

See Table 8-2 for third-order differential leveling methods and specifications.

Table 8-2 Third-Order Differential Leveling Specifications

Operation/Specification	Compensator-Level Three-Wire Observation	Compensator-Level Single-Wire Observation	Electronic/Digital Bar Code Level
Difference in length between fore and back sights, not to exceed per setup	10 m	10 m	10 m
Cumulative difference in length between fore and backsights, not to exceed per loop or section	10 m	10 m	10 m
Maximum sight lengths	90 m	90 m	90 m *(See Note 1)*
Minimum ground clearance of sight line	0.5 m	0.5 m	0.5 m
Maximum section misclosure	12 mm $\times \sqrt{D}$ *(See Note 2)*	12 mm $\times \sqrt{D}$ *(See Note 2)*	8 mm $\times \sqrt{D}$ *(See Note 2)*
Maximum loop misclosure	12 mm $\times \sqrt{E}$ *(See Note 3)*	12 mm $\times \sqrt{E}$ *(See Note 3)*	8 mm $\times \sqrt{E}$ *(See Note 3)*
Difference between top and bottom interval not to exceed	0.30 of rod unit	N/A	N/A
Collimation (Two-Peg) Test	Daily *(See Note 4)* (not to exceed 2 mm)	Daily	Daily
Minimum number of readings (Use repeat measure option for each observation)	N/A	N/A	3 *(See Note 5)*

Notes

1. Leveling staff in backlit condition may decrease maximum sight distance.
2. D = Shortest one-way length of section in km (section is defined as an unbroken series of setups between two permanent control points).
3. E = Length of loop in km (loop is defined as a series of setups closing on the starting point).
4. Readjust level if 2 mm in 60 m is exceeded.
5. If standard error exceeds 0.1 mm, continue repeat measurements until standard error is less than 0.1 mm.

8.6 Order G (General) Differential Leveling Surveys

Appropriate procedures for Order G (General) differential leveling are determined by the survey party chief based on the particular needs of the survey task being performed. Considerations in determination of procedures should include: objective of task, specific needs of the project and most efficient use of time.

See Section 12, "Engineering Surveys" and Section 13, "Construction Surveys" for tolerances and accuracy standards for specific types of surveys.

8.6-1 Applications

Order G (General) leveling surveys are generally used to provide elevations for:

- Supplemental Design Surveys
- Construction Layout
- Environmental Surveys
- GIS Data Surveys
- Topographic Survey Data Capture

8.6-2 Specifications

Methods:

- Compensator-type engineer's level (single-wire method) Philadelphia-style rod
- Compensator-type engineer's level (single-wire method) Lenker-style rod
- Compensator-type engineer's level (single-wire method) 7.5 m extendible fiberglass rod